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Surface-Soil Properties in Response to Silage Intensity under No-Tillage Management in the Piedmont of North Carolina

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Abstract

Although reduced tillage itself is beneficial to soil quality and farm economics, the amount of crop residues that is returned to the soil will likely alter the success of a particular conservation tillage system within a particular farm operation. There is a need for more information on multiple-year impacts of different residue retention systems on surface-soil properties in different environments. We investigated the impact of three cropping systems (gradient in residue returned to soil) on soil bulk density, aggregation, organic C and N, and microbial biomass and activity in a Piedmont soil in North Carolina. Most soil properties were not significantly affected by silage cropping intensity during this early stage in the study. There was a tendency for soil bulk density to be lower and soil organic C and N to be higher with lower silage cropping intensity as a result of greater crop residue returned to soil. Potential soil microbial activity was significantly greater in surface depths with lower silage cropping intensity. These early results suggest that greater quantities of crop residue returned to soil can have beneficial effects on soil quality, even in continuous no-tillage crop production systems.

Introduction

Soil quality is a concept based on the premise that management can deteriorate, stabilize, or improve soil ecosystem functions. Soil provides a medium for plant growth, regulates and partitions water flow in the environment, and buffers the fluxes of natural and xenobiotic compounds through decomposition and fixation processes (Larson and Pierce, 1991). The organic components of soil are important in providing energy, substrates, and the biological diversity necessary to sustain many soil functions.

Conservation tillage systems are now widely adopted by many producers, because they

- reduce fuel, time, and labor needed to make multiple tillage operations,
- reduce machinery wear
- allow for more timely planting of crops even under wetter soil conditions

- improve soil and water quality
- reduce runoff and make more effective use of precipitation
- improve wildlife habitat
- meet Farm Bill requirements

Although reduced tillage itself is beneficial to soil quality and farm economics, the amount of crop residues that is returned to the soil will likely alter the success of a particular conservation tillage system within a particular farm operation. Crop residues left at the soil surface as a surface mulch are important for feeding the soil biology, suppressing weed seed germination, and suppressing wide fluctuations in temperature and moisture that can limit plant development. There is a need for more information on multiple-year impacts of different residue retention systems on surface-soil properties in different environments.

Dairy producers in North Carolina rely on maize (*Zea mays* L.) and barley (*Hordeum vulgare* L.) silage as sources of high quality feedstuffs in their rations. High-intensity silage cropping is typically practiced to maximize the amount of feedstuffs produced per unit of land area. High-intensity silage cropping, however, leaves little residue at the soil surface, offering little buffer against equipment traffic. The lack of residue returned to the soil under high-intensity silage cropping brings into question issues of long-term compaction, water-use efficiency, nutrient cycling, and soil erosion when conservation tillage is used.

In this portion of the research endeavor, we investigated the impact of alternative cropping systems that returned more crop residues to the soil than the traditional maize-barley silage cropping system on surface-soil properties. Other portions of the research endeavor are concerned with agronomics, economics, water infiltration, and soil biological diversity.

Materials and methods

The site is located in Iredell County in the Southern Piedmont Major Land Resource Area of North Carolina (36 EN, 81 EW). Soils are mostly Fairview sandy clay loam (fine, kaolinitic, mesic Typic Kanhapludult) in Replication 1 and Braddock loam (fine, mixed, semiactive, mesic Typic Kanhapludult) in Replication 2. These soils are classified as well drained with moderate permeability. Mean annual precipitation is 48" (1220 mm) and temperature is 58 EF (14.4 EC).

Three cropping systems replicated twice were evaluated in - 1000'-long strips that were 50-75' wide (- 0.4-0.6 ha each). Plots were managed by the owner with his field equipment. Replication 1 was established in 1998 and Replication 2 was established in 2000. All plots were managed with no tillage for several years prior to, as well as during experimentation. Fertilizer as liquid dairy manure was applied in spring at a rate of 12,000 to 14,000 gallons $\cdot$ acre^{-1} $\cdot$ yr^{-1}, which was equivalent to 40-30-100-7 lb $\cdot$ acre^{-1} of N-P_2O_5-K_2O-S (45-15-93-8 kg N-P-K-S $\cdot$ ha^{-1}).

The three cropping systems were designed as a gradient in silage intensity and inversely related to the amount of crop residues returned to the soil. The traditional cropping system (high silage intensity) was maize silage planted in May and harvested in September followed by barley silage planted in November and harvested in April. This was a one-year rotation and had the least above-ground residue returned to the soil. A medium silage intensity system was maize silage planted in May and harvested in September followed by a winter cover crop [rye (*Secale cereale* L.) alone or rye plus crimson clover (*Trifolium incarnatum* L.)] killed by a herbicide in April. This was a one-year rotation and had a moderate level of crop residue returned. A low silage intensity system was maize silage planted in May and harvested in September followed by barley planted in November and harvested for grain in April. Barley straw was left in the field and a summer cover crop [sudangrass (*Sorghum sudanense* Hitchc.) or sunnhemp (*Crotalaria juncea* L.)] planted in May and killed by frost in October. The summer cover crop was left in the field and followed by planting of rye as a winter cover crop in November, which was killed by a herbicide in April and left in the field. This was a two-year rotation and had the highest level of crop residue returned. Expressed as silage cropping intensity, treatments had 0.5 (low silage intensity), 1 (medium silage intensity), and 2 (high silage intensity) silage crops harvested per year.

Surface residue and soil were sampled in December 2000 and February 2002. In December 2000, plots were sampled in duplicate by splitting the plot in half to assess within-plot variability. For each sample collected, eight sites located - 70' (20 m) apart were composited. Surface residue was collected from 64 sq. in. (20 x 20 cm) areas by first removing green plant material above - 1.5"-height (4 cm) and then collecting all surface residue to ground level by cutting with a battery-powered hand shears. Following surface residue removal, a soil core [1.6" diam (4-cm diam)] was sectioned into depths of 0-1.2, 1.2-2.4, 2.4-4.7, and 4.7-7.9" (0-3, 3-6, 6-12, and 12-20 cm). Surface residue was dried at 158 E F (70 EC) for several days, ground to <1/32" (1 mm), and analyzed for total C and N with dry combustion. Soil was dried at 131 EF (55 EC) for 3 days, initially passed through a sieve with openings of 3/16" (4.75 mm) to remove stones, a subsample ground in a ball mill for 5 minutes, and analyzed for total C and N with dry combustion. Soil bulk density was calculated from the total dry weight of soil and volume of coring device. Clay content was determined with a hydrometer at the end of a 5-h settling period following dispersion in 0.01 *M* $Na_4P_2O_7$.

Aggregate distribution and stability analyses followed a procedure outlined in Franzluebbers et al. (2000b). Dry aggregate distribution was determined by placing a 3.5-oz. portion (100 g) of soil on top of a nest of sieves [7.9" (20 cm) diam with openings of 1/24, 1/100, and 2/1000" (1.0, 0.25, and 0.05 mm)], shaking for 1 min at level 6 on a CSC Scientific Sieve Shaker (Catalogue No. 18480), and weighing soil retained on the 1.0-, 0.25-, and 0.05-mm screens and that passing the 0.05-mm screen. Water-stable aggregate distribution was determined from the same soil sample used for dry aggregate distribution placed on top of a nest of sieves [6.9" (17.5-cm) diam with openings of 1.0 and 0.25 mm), immersed directly in water, and oscillated for 10 min [3/4" (20 mm) stroke length, 31 cycles · min^{-1}]. After removing the two sieves and placing them in an oven to dry, water containing soil passing the 0.25-mm sieve was poured over a 0.05-mm sieve, soil washed with a gentle stream of water, and the soil retained transferred into a drying bottle with a small stream of water. The <0.05-mm fraction was calculated as the difference between initial soil weight and summation of the other fractions. All fractions were oven-dried at 131 EF (55 EC) for 3 d.

Mean-weight diameter of both dry- and water-stable aggregates was calculated by summing the products of aggregate fractions and mean diameter of aggregate classes. Macroaggregates were defined as soil retained on 1.0- and 0.25-mm sieves. Large macroaggregates were defined as soil retained on the 1.0-mm sieve. Stability of macroaggregates was calculated as the weight of water-stable macroaggregates divided by the weight of dry-stable macroaggregates. Stability of mean-weight diameter was calculated as water-stable mean-weight diameter divided by dry-stable mean-weight diameter.

Carbon mineralization was determined by placing two 1- to 2-oz. (20- to 55 g, inversely related to soil organic C concentration) soil subsamples in 1/4-cup (60 mL) glass jars, wetting to 50% water-filled pore space, and placing them in a 1-qt. canning jar along with 2 tsp. (10 mL) of 1 *M* NaOH to trap CO_2 and a vial of water to maintain humidity. Samples were incubated at 77

EF (25±1 EC) for up to 24 d. Alkali traps were replaced at 3 and 10 d of incubation and CO_2-C determined by titration with 1 *M* HCl in the presence of excess $BaCl_2$ to a phenolphthalein endpoint. Basal soil respiration was calculated as the linear rate of C mineralization between 10 and 24 d. At 10 d, one of the subsamples was removed from the incubation jar, fumigated with $CHCl_3$ under vacuum, vapors removed at 24 hr, placed into a separate canning jar along with vials of alkali and water, and incubated at 25 EC for 10 d. Soil microbial biomass C was calculated as the quantity of CO_2-C evolved following fumigation divided by an efficiency factor of 0.41 (Franzluebbers et al., 1999).

Data were analyzed for variance due to silage cropping intensity within each depth using the general linear models procedure of SAS (SAS Institute Inc., 1990). Differences among silage cropping intensity treatments were considered significant at P#0.1.

Results and discussion

Soil bulk density

We note here up-front that the differential implementation of the two replications in this experimental design does not allow a strict temporal evaluation of the treatments. Sampling in December 2000 was after 3 years of treatment in Replication 1 and after 1 year of treatment in Replication 2. Sampling in February 2002 was after 4 years of treatment in Replication 1 and after 2 years of treatment in Replication 2. The value of this experiment will be enhanced with time. Despite this, the changes in soil-surface properties during the first few years of evaluation should be revealing towards possible future effects.

Soil bulk density increased with depth under all management systems (Table 1). This change in bulk density with depth is a common observance in natural ecosystems, in managed grasslands, and under conservation tillage (Franzluebbers et al., 2000). The depth distribution of soil bulk density highlights the need to assess potential compaction problems under conservation tillage systems at a finer spatial scale than simply the traditional plow layer.

Soil bulk density in December 2000 was greater under high than under low silage cropping intensity at depths of 0-3, 3-6, and 6-12 cm, but not at 12-20 cm (Table 1). Soil bulk density under medium silage intensity was not different from that under high silage intensity at any depth interval, but was greater than under low silage intensity at 3-6- and 6-12-cm depths. Taken to a depth of 20 cm, soil bulk density was significantly greater under medium and high silage intensity than under low silage intensity.

Soil bulk density in February 2002 was not affected by silage cropping intensity (Table 2). The least significant difference among silage cropping intensity treatments was higher in the February 2002 sampling than in the December 2000 sampling. This was because experimental units were not split into duplicate strips during the February 2002 sampling as during the December 2000 sampling.

When mean values were plotted for each treatment and year since establishment, a significant temporal change in soil bulk density occurred between low and high silage cropping intensity (Fig. 1). These results suggest that compaction was occurring at a slow rate with high silage cropping intensity, but that compaction could be alleviated by low silage cropping intensity with high surface residue return. The slow conversion of organic matter from crop residues into soil organic C, especially at the soil surface, can lead to a large reduction in soil bulk density (Franzluebbers et al., 2001). Organic matter has a much lower specific density than mineral soil and the incorporation of organic matter with soil often leads to a more porous soil matrix as a result of soil faunal and microbial activity, which fabricate stable aggregates with large voids in between them.

Soil texture and aggregation

Clay, silt, and sand proportions in soil were unaffected by management (Table 1). Clay-sized particles (<2 µm) averaged 25% of the soil, while silt-sized particles (2-50 µm) averaged 21%, and sand-sized (>50 µm) particles averaged 54%.

At a depth of 0-20 cm, aggregate distribution and stability sampled in December 2000 were not significantly different among silage cropping intensity treatments (Table 1). At a depth of 0-3 cm, stability of macroaggregates was greater under low and medium silage intensity than under high silage intensity. At this depth, stability of mean-weight diameter of aggregates was also greater under medium than under high silage intensity. Overall, few significant changes in aggregate distribution and stability occurred. Aggregate distribution and stability can be viewed as secondary response variables that are dependent upon surface residue retention, soil organic C, soil microbial activity, and compaction. We expect that aggregate distribution and stability will improve slowly with higher residue-retention management systems.

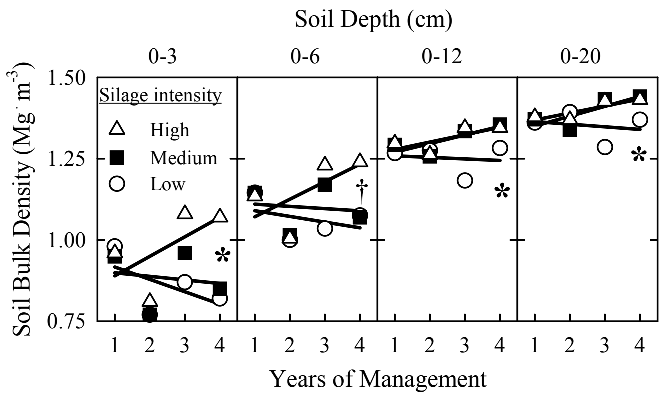

Figure 1. Soil bulk density within the surface 7.9" (20 cm) of soil as affected by number of years under a particular silage intensity. † and * indicate significance at P#0.1 and P#0.05, respectively, between regression lines.

Soil biochemical properties

Soil organic C and N were highly stratified with depth under all management systems (Table 3). This stratification with depth is common in many undisturbed ecosystems, including native forests and grasslands, managed grasslands, and cropping systems with conservation tillage. Soil organic C and N were highly stratified with depth on this farm as a result of long-term management with conservation tillage. Although not significant, soil organic C and N tended to be higher with lower silage cropping intensity, especially nearest the soil surface. Greater quantities of crop residue are returned to the soil with lower silage cropping intensity. With time, we expect that soil organic C and N will become significantly greater with low than with high silage cropping intensity.

The C:N ratio of soil organic matter was little affected by depth of sampling or by management (Table 3).

Soil microbial biomass C was highly stratified with depth, similar to that of soil organic C and N (Table 3). The only significant management effect occurred at a depth of 12-20 cm, where soil microbial biomass was greater under low than under medium and high silage cropping intensity. The portion of soil organic C as microbial biomass C was relatively uniformly distributed with depth and was little affected by management. Although soil microbial biomass represented only 4.7% of the soil organic C pool, it plays a major role in organic matter decomposition and nutrient cycling as the agent that mediates elemental transformations. Changes in soil microbial biomass may be an early indicator of long-term changes in soil organic matter due to a particular management system (Powlson et al., 1987).

The flush of CO_2 following rewetting of dried soil was highly stratified with depth, similar to that of soil microbial biomass and total organic C (Table 3). The flush of CO_2 is an indicator of both potential soil microbial activity and soil microbial biomass (Franzluebbers et al., 2000a). Even at an early stage in this study, the flush of CO_2 was greater under lower than higher silage cropping intensity at depths of 0-3 and 3-6 cm. These surface changes led to significant changes even when considering the 0-20 cm depth. Potential C mineralization has been found to be a sensitive indicator of tillage management in other studies as well (Franzluebbers and Arshad, 1996; Franzluebbers et al., 1999).

Conclusions

Sampling of surface-soil properties at the end of the first few years of implementation of a study to evaluate the effects of alternative silage crop management systems suggested that soil physical properties such as bulk density and aggregation and soil biochemical properties such as organic C, microbial biomass C, and mineralizable C would respond positively and lead to an improvement in soil quality. Sufficient quantities of residues returned to the soil are necessary for organic matter transformations to facilitate the development of an improved soil condition. This study will continue to be able to more conclusively identify the impacts of silage cropping intensity on soil and water conservation and farm economics.

References

Franzluebbers, A.J., and M.A. Arshad. 1996. Soil organic matter pools with conventional and zero tillage in a cold, semiarid climate. Soil Till. Res. 39:1-11.

Franzluebbers, A.J., R.L. Haney, C.W. Honeycutt, H.H. Schomberg, and F.M. Hons. 2000a. Flush of carbon dioxide following rewetting of dried soil relates to active organic pools. Soil Sci. Soc. Am. J. 64:613-623.

Franzluebbers, A.J., G.W. Langdale, and H.H. Schomberg. 1999. Soil carbon, nitrogen, and aggregation in response to type and frequency of tillage. Soil Sci. Soc. Am. J. 63:349-355.

Franzluebbers, A.J., J.A. Stuedemann, and S.R. Wilkinson. 2001. Bermudagrass management in the Southern Piedmont USA. I. Soil and surface residue carbon and sulfur. Soil Sci. Soc. Am. J. 65:834-841.

Franzluebbers, A.J., S.F. Wright, and J.A. Stuedemann. 2000b. Soil aggregation and glomalin under pastures in the Southern Piedmont USA. Soil Sci. Soc. Am. J. 64:1018-1026.

Larson, W.E., and F.J. Pierce. 1991. Conservation and enhancement of soil quality. *In* Evaluation for sustainable land management in the developing world. Vol. 2, IBSRAM Proc. 12 (2). Bangkok, Thailand. Int. Board for Soil Res. and Management.

Powlson, D.S., P.C. Brookes, and B.T. Christensen. 1987. Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. Soil Biol. Biochem. 19:159-164.

SAS Institute Inc. 1990. SAS user’s guide: Statistics. Version 6 ed. SAS Inst., Cary, NC.

Table 1. Soil physical properties within depth sections as affected by silage cropping intensity in December 2000.

Soil depth		Silage cropping intensity			
Inches	cm	Low	Medium	High	LSD $_{(P=0.1)}$
		Soil bulk density ($Mg \cdot m^{-3}$)			
0-1.2	0-3	0.93	0.95	1.02	0.08 †
1.2-2.4	3-6	1.25	1.36	1.35	0.09 †
2.4-4.7	6-12	1.36	1.47	1.46	0.08 *
4.7-7.9	12-20	1.47	1.53	1.52	0.10
0-7.9	0-20	1.32	1.40	1.40	0.07 †
		Clay content ($g \cdot g^{-1}$)			
0-1.2	0-3	0.22	0.23	0.24	0.06
1.2-2.4	3-6	0.20	0.21	0.23	0.05
2.4-4.7	6-12	0.22	0.24	0.24	0.08
4.7-7.9	12-20	0.24	0.31	0.29	0.08
0-7.9	0-20	0.22	0.27	0.26	0.06
		Water-stable macroaggregates ($g \cdot g^{-1}$)			
0-1.2	0-3	0.77	0.76	0.73	0.08
1.2-2.4	3-6	0.76	0.79	0.78	0.05
2.4-4.7	6-12	0.70	0.72	0.75	0.04 *
4.7-7.9	12-20	0.66	0.62	0.61	0.03 *
0-7.9	0-20	0.70	0.69	0.69	0.03
		Stability of macroaggregates [g (wet) $\cdot g^{-1}$ (dry)]			
0-1.2	0-3	0.86	0.88	0.81	0.05 *
1.2-2.4	3-6	0.85	0.87	0.85	0.03
2.4-4.7	6-12	0.79	0.83	0.82	0.05
4.7-7.9	12-20	0.75	0.72	0.71	0.04 †
0-7.9	0-20	0.79	0.79	0.78	0.03
		Water-stable mean-weight diameter of aggregates (mm)			
0-1.2	0-3	1.22	1.26	1.20	0.19
1.2-2.4	3-6	1.28	1.36	1.32	0.14
2.4-4.7	6-12	1.12	1.27	1.27	0.15 †
4.7-7.9	12-20	1.04	0.96	0.92	0.11 †
0-7.9	0-20	1.12	1.15	1.12	0.10
		Stability of mean-weight diameter [mm (wet) $\cdot mm^{-1}$ (dry)]			
0-1.2	0-3	0.69	0.77	0.66	0.09 *
1.2-2.4	3-6	0.69	0.74	0.70	0.07
2.4-4.7	6-12	0.64	0.71	0.67	0.07 †
4.7-7.9	12-20	0.58	0.55	0.53	0.05
0-7.9	0-20	0.62	0.65	0.61	0.05

† and * indicate significance at P#0.1 and P#0.05, respectively.

Table 2. Soil bulk density within depth sections as affected by silage cropping intensity in February 2002.

Soil depth		Silage cropping intensity			
Inches	cm	Low	Medium	High	LSD $_{(P=0.1)}$
		Soil bulk density ($Mg \cdot m^{-3}$)			
0-1.2	0-3	0.80	0.81	0.94	0.24
1.2-2.4	3-6	1.28	1.27	1.31	0.18
2.4-4.7	6-12	1.52	1.56	1.48	0.25
4.7-7.9	12-20	1.53	1.51	1.54	0.19
0-7.9	0-20	1.38	1.38	1.40	

Table 3. Soil biochemical properties within depth sections as affected by silage cropping intensity in December 2000.

Soil depth		Silage cropping intensity			
Inches	cm	Low	Medium	High	LSD $_{(P=0.1)}$
		Soil organic C ($mg \cdot g^{-1}$)			
0-1.2	0-3	38.2	33.3	30.0	12.7
1.2-2.4	3-6	16.6	14.6	15.9	2.2
2.4-4.7	6-12	10.3	10.4	10.8	2.6
4.7-7.9	12-20	7.6	6.4	6.8	1.6
0-7.9	0-20	12.9	11.6	11.8	2.4
		Total soil N ($mg \cdot g^{-1}$)			
0-1.2	0-3	4.19	3.47	3.21	1.52
1.2-2.4	3-6	1.75	1.52	1.74	0.30
2.4-4.7	6-12	1.05	1.07	1.10	0.30
4.7-7.9	12-20	0.77	0.63	0.63	0.16
0-7.9	0-20	1.35	1.18	1.21	0.28
		C:N of soil organic matter ($g \cdot g^{-1}$)			
0-1.2	0-3	9.2	9.6	9.4	0.5
1.2-2.4	3-6	9.5	9.7	9.2	0.5
2.4-4.7	6-12	10.2	9.8	9.9	0.9
4.7-7.9	12-20	9.9	10.3	10.8	0.9 †
0-7.9	0-20	9.6	9.8	9.8	0.4
		Soil microbial biomass C ($\mu g \cdot g^{-1}$)			
0-1.2	0-3	1711	1515	1340	479
1.2-2.4	3-6	877	836	781	168
2.4-4.7	6-12	422	471	532	126
4.7-7.9	12-20	373	288	305	59 *
0-7.9	0-20	599	550	556	82
		Portion of soil organic C as microbial biomass C ($mg \cdot g^{-1}$)			
0-1.2	0-3	45.4	45.7	45.4	6.1
1.2-2.4	3-6	53.2	58.2	49.6	14.2
2.4-4.7	6-12	40.7	45.7	49.5	7.9 †
4.7-7.9	12-20	49.8	45.0	45.4	7.3
0-7.9	0-20	46.7	47.5	47.3	3.8
		Flush of CO_2-C following rewetting of dried soil ($\mu g \cdot g^{-1} \cdot 3\ d^{-1}$)			
0-1.2	0-3	544	643	402	153 *
1.2-2.4	3-6	291	293	220	45 *
2.4-4.7	6-12	148	173	150	41
4.7-7.9	12-20	99	81	88	33
0-7.9	0-20	188	198	160	29 *

† and * indicate significance at P#0.1 and P#0.05, respectively.